UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
Forest Insect and Disease Management
P. O. Box 5895, Asheville, NC 28803

REPLY TO: 3400 Forest Insect and Disease Management

September 14, 1979

Report No. 79-1-37

SUBJECT: Oak Decline on the Wayah RD, Nantahala NF, North Carolina 1979

TO: George A. Olson, Forest Supervisor, NFs in N.C.

On September 7, 1979, Bob Anderson, Pathologist, from our office and Don Rogers from the North Carolina Forestry Division met with Fred Foster to look at some dying oaks.

The shade trees they looked at were older oaks that had sustained root damage and site changes. The use of weed and feed probably contributed to some of the mortality.

The declining oaks were stressed trees that were dying primarily because of environmental conditions, even though many of them had root diseases and stem insect attacks. Oak decline is described very well in the attached publication by Dr. John M. Skelly (attachment 1). You have a carbon copy of the described situation. A case study in Pennsylvania is also attached (attachment 2).

The main factor which contributed to the decline seems to be lack of moisture. Attachment 3 compares 1978 to 1941 which was the driest year in the Coweeta records. Attachment 4 compares dormant to growing season moisture for 1964 to 1979. Attachment 5 shows the 2nd to 9th driest month for 1973-79 (All of these weather records were provided by Lloyd W. Swift, Coweeta Hydrologic Laboratory.). When the dry periods of 1975-77, a major drought in 1978, and no unusual dry periods in 1973-74 are compared, a good case for gradual buildup of stress and the resulting mortality can be made. Current years records show a reduction in moisture stress and should result in reduced mortality.

The decline has some benefit, in that it thins out weakened trees and provides additional growing space for healthy trees.

No significant disease or insect problems, such as oak wilt, were found on the dead or dying trees.

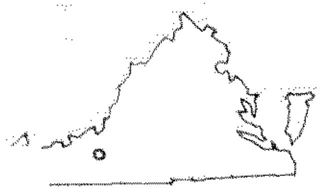
We have ordered copies of the book "Insects and Diseases of Kentucky" per Fred's request. They will be sent to the district in the near future.

Please feel free to give us a call if we can provide additional information.

Robert L Anderson
For HAROLD W. FLAKE
Field Representative

Enclosures (5)

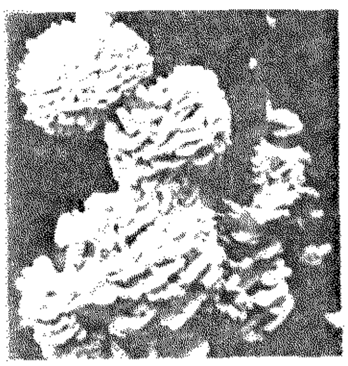
cc: Lloyd Swift, Coweeta Hydrologic Lab., Franklin, NC
Fred Foster, Wayah RD, Nantahala NF
Walt Smith, NFsNC
Coleman Doggett, NC Div. of For., Raleigh, NC
Don Rogers, NC Div. of For., Morganton, NC



Forest Tree Diseases of Virgini

RUST

DECLINE



DECAY

January 1972 MR-FTD-4

Oak Decline

by

John M. Skelly
Extension Specialist, Plant Pathology
Virginia Polytechnic Institute
Blacksburg, Virginia

Oak is the most important hardwood species found on the North American continent. In Virginia, 53.2 percent of the growing stock is oak and the red oak species (red, black, scarlet, pin, cherrybark, and shumard) comprise about 44 percent of the oak population.

During the past few decades oaks throughout the mountainous sections of the eastern United States have been declining and dying at alarming rates. This loss of oaks has been termed oak decline, oak dieback, or oak mortality. Some confusion has developed over these various descriptive terms but all define the same problem.

Figure 1. Initial stages of oak decline--thin foliage, and twig die

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. W. E. Skelton, Dean, Extension Division, Cooperative Extension Service, Virginia Polytechnic Institute and State

The overall impact of this disease of oak on our forests is undetermined, however, some specific facts are available concerning the areas affected:

1. The mortality problem is defined as involving 5 percent (more commonly 20-50 percent) of the oaks in a unit area in a given year.
2. Heavy losses within the red oak group have occurred on nearly 200,000 acres in one northeastern state since 1953.
3. Losses of saw timber in severely affected stands have ranged from 3,000 to 7,000 board feet per acre.
4. Many pole sized stands have been severely affected with 300 or more oaks dying per acre.
5. Mortality areas range from 30 to 15,000 acres.

Recent surveys in Virginia suggested that oak decline is to be considered the most devastating disease since the days of the chestnut blight epidemic. Extensive mortality is present in varying degrees of intensity over approximately 104,000 acres on the George Washington National Forest and at least 5,900 acres of scarlet oaks are affected on the Jefferson National Forest.

Areas of mortality on the George Washington National Forest range in size from 150 to 6,000 acres. Decline areas on the Jefferson National Forest ranged in size from 280-1,200 acres.

Figure 2. Intermediate stages of oak decline--stagheading or death of large branches, water sprouts on main stem, and premature fall coloration.

Range:

Declining oaks can be found in hardwood forests from New York to southwestern Virginia. Although the disease is evident on all sites, severe mortality of scarlet oak (Quercus coccinea) is usually confined to poor ridge sites or areas of shale-derived soil where extreme soil moisture deficits are prolonged.

Suscepts:

Oak decline affects species of the red oak group (scarlet, pin, red and black oak) more so than those of the white oak group (white, chestnut, swamp white oak). Nearly three-fourths of the trees affected have been in the red oak group although reports of mortality of white oak have recently been recorded.

Symptoms:

Oak decline is characterized by a slow progression of symptoms involving decline or loss of vigor, dieback and mortality. Affected trees may exhibit thin, chlorotic foliage, reduced growth, and twig dieback during the early stages of decline (Figure 1). Trees in intermediate stages of decline exhibit branch dieback, production of a few water sprouts on the main stem, leaf wilt, browning, and premature leaf coloration in the fall (Figure 2). Advanced stages of decline involve the prolific production of water sprouts, the wilt and death of these, death of the cambium and roots, and eventual mortality of the entire tree (Figure 3). The declining trees are rapidly attacked by various decay fungi and fruiting bodies of these fungi are quite common on the basal portions of dying trees. All stages of oak decline are

Figure 3. Advanced stages of oak decline--affected trees have dead crowns, a few water sprouts persist, and the weakened tree is susceptible to attack by beetles and decay fungi.

usually found in any specific area and older trees appear to be more severely affected than younger, more vigorous individuals. Affected trees show a m ked reduction in annual growth during all stages of the decline.

Cause:

Decline of oak is caused by several factors that lead to the depletion of food reserves (carbohydrates). Any agent causing a decrease in the production of starch (i.e. destruction of photosynthetic or food making capacity) will lead to decline and death of affected trees. Affected trees usually refoliate after initial defoliation by frost or insects and this in turn causes a further depletion of food reserves. Annual recurrence of contributing factors eventually will place the tree in such a weakened condition that secondary agents can readily attack the tree and result in further deterioration. If these processes continue, death of the entire tree follows.

The primary agents responsible for this depletion of carbohydrate reserves are insect defoliation, late spring frost, and/or mid- to late-summer droughts accompanied by unfavorable soil conditions. Trees weakened by these agents are then subject to attack by wood borers and root rot fungi.

Control:

Since oak decline is caused by many factors of the environment no specific control recommendations can be made. In areas where severe insect defoliation was the leading causal factor, aerial spraying with insecticides has alleviated the decline. However, spraying is costly and should be done where oak quantity and quality is high. Before aerial spraying is conducted, contact must be made with the local County Extension or District Forest office to obtain the necessary state and federal regulations.

In areas where oak decline is severe, the red oak group should not be favored in timber management programs. This is particularly true in areas with high scarlet oak populations.

Prompt clear cut and/or salvage operations are recommended in severe decline areas as affected trees soon deteriorate beyond the worth of good fireplace wood.

KEYS TO PROPER USE OF PESTICIDES

1. Read the label on each pesticide container before each use. Follow instructions to the letter; heed all cautions and warnings, and note precautions about residues.
2. Keep pesticides in the containers in which you bought them. Put them where children or animals cannot get to them, preferably under lock and away from food, feed, seed, or other material that may become harmful if contaminated.
3. Dispose of empty containers in the manner specified on the label. If disposal instructions are not printed on the label, burn the containers where smoke will not be a hazard, or bury them at least 18" deep in a place where water supplies will not be contaminated.

SEE YOUR DOCTOR IF SYMPTOMS OF ILLNESS OCCUR DURING OR AFTER USE OF PESTICIDES.

OAK MORTALITY IN PENNSYLVANIA

A TEN–YEAR STUDY

James O. Nichols

ABSTRACT.—The primary cause of crown dieback and mortality in the red oak group (Quercus rubra *L.*, Q. coccinea *Muenchh., and* Q. velutina *Lam.) was determined to be insect and spring-frost defoliations. An oak leaf tier* (Croesia semipurpurana [*Kearf.*]) was the most important *agent, due to its selective feeding habits within this group. Other environmental, site, and pathogenic factors contributed occasionally to deterioration but did not initiate the decline process. Mortality ceased and recovery of declining oaks began when defoliation ceased, in spite of the most extended period of drought on record. Two or three consecutive years of 60 percent to 100 percent defoliation predisposed trees, or crown portions, to killing attacks by the two-lined chestnut borer* (Agrilus bilineatus [*Web.*]). *Pure stands of the red oak group suffered the greatest losses and should be avoided in silvicultural management. Mortality of chestnut oak* (Q. prinus *L.*) *and associated white oak* (Q. alba *L.*) was due principally to continuous *attacks of a pit-making oak scale* (Asterolecanium minus [*Ratz.*]).

THERE has been a growing concern since 1951 over the extensive dying and decline of oaks in many forested areas of Pennsylvania. Similar mortality has occurred in portions of New York and New Jersey (*6*) and in West Virginia (*8,19*). At least three-fourths of the timber affected has been in the red oak group, i.e., northern red oak (*Quercus rubra* L.), scarlet oak (*Q. coccinea* Muenchh.), and black oak (*Q. velutina* Lam.).

Periodic speculations as to the causal agents have tended to implicate nearly every conceivable factor, including complex ecological relationships. Many of these opinions, however, have largely overlooked the fact that mortality in the red oak group is not a new problem. Hopkins (*10*) in 1902 mentioned that serious losses of oaks had occurred for many years in portions of the eastern and northern United States. The Pennsylvania Department of Forests and Waters has records of extensive oak mortality occurring during the 1930's and 1940's.

Insect defoliation, frost damage, and drought have always been prime suspects. Knull (*12*), and in his unpublished reports, found trees of the red oak group dead and dying over several thousand acres in eastern and central Pennsylvania. He attributed death to several consecutive years of heavy defoliation by several species of Lepidoptera and a severe late spring frost in 1930. Knull believed there may have been possible adverse effects from the 1930-1931 drought, although he found annual tree ring growth had been declining in most areas since 1926.

Several investigations (*1,11,14,19*) have indicated that drought and secondary causes were probably responsible for the death of numerous red oak group species, predominantly scarlet oak, in the Appalachians. Beal (*3*) observed that frost damage may have

THE AUTHOR is forest entomologist, Pennsylvania Dept. Forests and Waters, Harrisburg. He thanks W. E. Waters and D. R. Houston of the Northeastern Forest Expt. Sta., U. S. Forest

severe effects and stated that 3 million board feet of white oak (*Q. alba* L.) died in the year following two days of killing frosts in late May.

Staley (*17,18*) conducted investigations of red and scarlet oak decline in central Pennsylvania and West Virginia in the 1950's. He concluded that carbohydrate deficiencies, primarily brought about by oak leaf roller defoliations, resulted in initial decline symptoms, and that other factors such as root rot, drought, and frost were contributory but not primarily causal. He also pointed out that recent European investigators have treated similar oak decline problems as primarily entomological.

The current study was initiated in 1957 to determine the effects on oaks from insect and frost defoliations and drought. Conclusions reached were the result of exploring decline and mortality in large blocks throughout the state.

Extent of Mortality

The mortality problem is defined as involving the death of 5 percent or more (commonly 20 to 50 percent) of the oaks in a unit area in a given year. Heavy loss of red oak group species has occurred on nearly 200,000 acres in the state since 1953, and considerably more could undoubtedly be added from unreported cases and from areas where yearly oak losses were under 5 percent. Losses of sawtimber in severely affected stands during a mortality period has ranged from 3,000 to 7,000 board feet per acre. In addition, many pole-timber stands have been decimated, frequently involving 300 or more oaks per acre. Mortality areas have ranged in size from 30 to 15,000 acres.

In the red oak group, all age and crown classes are commonly affected. Killed trees exhibit two to three years of serious radial growth reduction, frequently preceded by two to ten years of gradual loss in radial growth. Symptoms of crown decline normally start in the top portion with several dead branches, reduced terminal growth, chlorosis, and stunting of foliage with reduced density. Symptoms progress downward and inward in subsequent years, or in one year, until all that may remain is a stagheaded tree with sprouting on the stem and larger branches. Serious dieback is evident on over one million acres. Staley (*18*) listed other decline symptoms as being rootlet mortality, lack of starch reserves, and reduced acorn production.

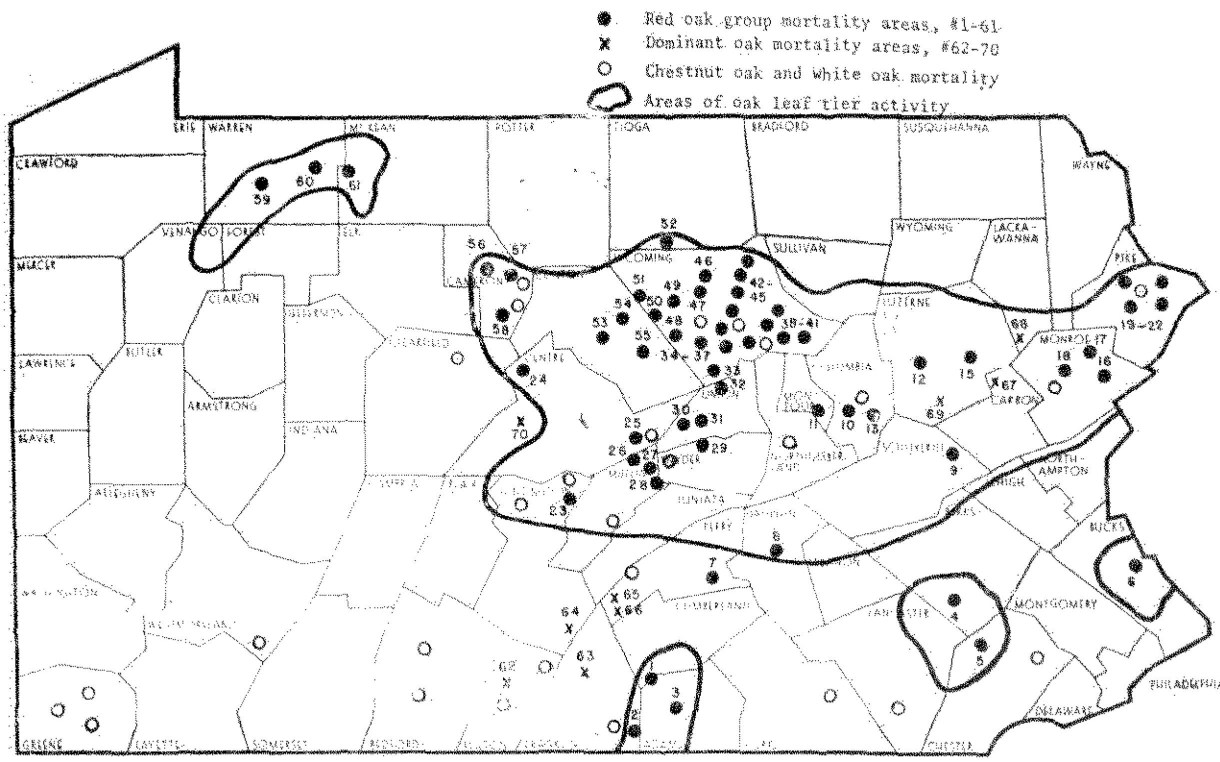


Fig. 1.—Oak mortality study areas in Pennsylvania. All affected stands were in a mixed oak type. Most of the northern tier of counties and some in the western third of the state are in the northern hardwood type.

Declining oaks failed to yield *Ceratocystis fagacearum* (Bretz) Hunt, the cause of oak wilt (*18*). Symptoms of this disease are dissimilar to those of oak decline. The typical oak wilt tree is normally not "declining" when struck by the disease. Losses due to oak wilt in Pennsylvania have been less than 1 percent of the total mortality in the red oak group.

Mortality has occasionally been observed on dominant trees only and unselective as to species of oak. Several areas totaling 1,000 acres were recorded in this category. These trees usually appeared healthy before an abrupt decline period of one or two years. Mortality to chestnut oak (*Q. prinus* L.) and associated white oak has occurred on over 50,000 acres since 1953, with noticeable dieback and other decline symptoms evident on 2 million acres.

Methodology

Case histories were maintained in 70 areas experiencing red oak group or dominant oak mortality and in several other areas where chestnut oak and white oak mortality occurred (Fig. 1). Degree of defoliation in each area from 1953 to 1966 was observed in 62 percent of the total recordings, and the remainder was obtained from previous survey records. Recordings were made both before and after initial mortality occurred. These locations constituted 69 percent of all known similar mortality areas in the state. Reliable defoliation data was unavailable for the remainder.

Each contiguous mortality area was treated as one unit, regardless of size. From 3 to 15 observation points of 1/5 acre each were established in each area for determining defoliation and mortality ratios. For comparison 12 plots with negligible defoliation, decline, and mortality were established as near as possible to major mortality centers.

The average insect defoliation in the observation points was listed as either moderate (25-60 percent) or heavy (over 60 percent). Light defoliation (under 25 percent) was omitted from final data as it caused insignificant decline symptoms and occurred in most oak stands every year. Spring frost damage was recorded if serious enough over at least 25 percent of the crown canopy as to cause either defoliation, killing of expanding buds, or branch mortality. Tree mortality was designated as moderate (5 to 10 percent of oaks killed) or major (over 10 percent killed in any one year).

The rates of annual ring growth were determined from borings and cut trees, using a five-year period before decline set in as normal growth. In each mortality area, there were 20 to 40 of these counts. Rainfall deficiencies during the growing season, April through September, were obtained from U. S. Weather Bureau records (*20*). The nearest recording station was used; in several instances, interpolations were made from two or three stations.

Recovery rates of red, scarlet, and black oaks were studied from 14 1/5-acre plots. These were established over a 6,000-acre area following heavy mortality in 1959 and 1960. Various timber size classes, crown classes, sites, and exposures were represented. Recovery, as well as decline, was determined from radial growth measurements and crown conditions. Five categories of crown vigor class were used. Briefly, these were: (1) healthy crown with very few dead branches; (2) good crown but occasional dieback in upper portion, foliage density subnormal; (3) fair to poor crown with moderate to severe dieback, foliage density and color subnormal, some sprouting; (4) very poor crown with half of it dead, foliage density, color and size subnormal, sprouting heavy; (5) apparently dying trees with crown mostly dead, tree subsisting on epicormic branching.

Table 1.—Summary of Data from 61 Red Oak Group Mortality Areas, 1953-1966 (All Timber Size and Crown Classes Affected)

1. Average area affected by mortality: 1640 acres; range: 30-15,000 acres.
2. Average duration of mortality period (over 5 percent of oaks killed per year): 3.4 years; range: 1-6 years.
3. Average duration of major mortality (over 10 percent of oaks killed per year): 1.3 years; range: 1-3 years (from 53 areas).
4. Number of recurring mortality cases: 29 (total of 90 mortality periods in the 61 areas).
5. Average number of consecutive years of heavy defoliation immediately preceding mortality: 2.1; range: 1-3.
6. Average number of consecutive years of moderate defoliation preceding heavy defoliation in (5): 3.3; range: 0-7 (in 13 percent of the areas there was no moderate defoliation prior to the heavy attack).
7. Cases where at least one year of the heavy defoliation in (5) was caused by frost damage: 22 percent.
8. Cases in which a mortality period was immediately preceded by two consecutive years of frost damage (no insect defoliation): 8 percent.
9. Average number of years of continuing mortality following cessation of heavy defoliation: 1.1; range: 0-3.

Results and Discussion

The major findings on the impact of insect defoliators, frost damage, and drought on oaks were:

1. Mortality in all 70 red oak group and dominant oak areas was preceded by heavy insect defoliation or severe frost damage. There were two instances where additional mortality occurred when trees were extensively damaged by ice and hail. Nearly all dying and recently killed trees were infested with the two-lined chestnut borer (*Agrilus bilineatus* [Web.]). In most areas mortality ceased after one to four years, but occasionally the time was extended until virtually all of the red oak group was dead.

2. In the red oak group areas (#1-61), insect defoliation was the major force implicated, with frost damage contributing to tree decline in 54 of the areas at least once during the 14-year period (Table 1). Heavy insect and frost defoliations early in the growing season had the same general effects. It generally required two consecutive years of 60 to 100 percent spring defoliation to initiate mortality. Major mortality in 23 of the 90 mortality periods did not occur until after a third severe defoliation. Most areas showed at least two to three years of moderate insect defoliation prior to the heavy attacks. Only rarely was mortality initiated by one heavy stripping preceded by several years of moderate defoliation. Continuous moderate defoliation did not kill trees outright, but it started

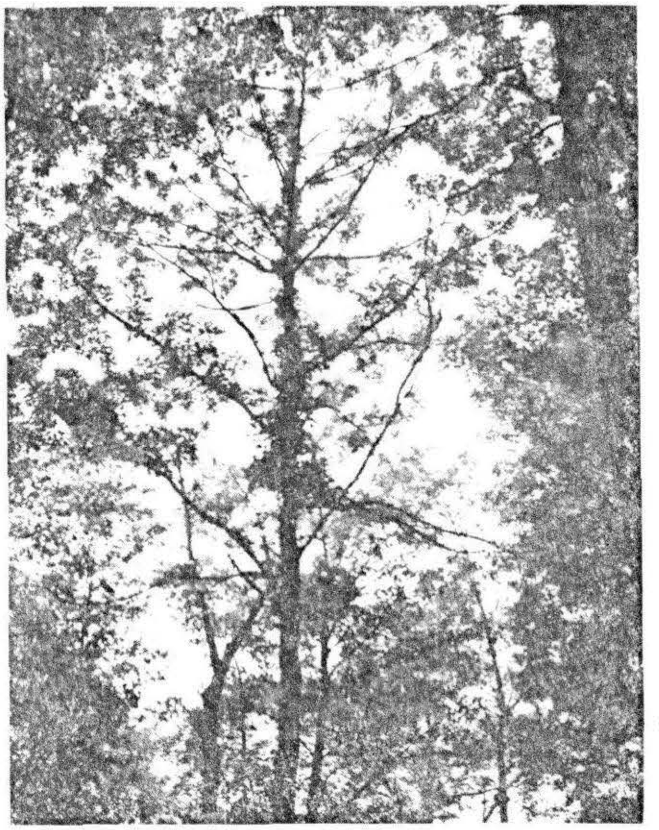


Fig. 3.—A temperature of 15° F on May 10, 1966 killed expanding buds on this 12-inch d.b.h. northern red oak, resulting in considerable twig and branch mortality. The tree occurred on a good red oak site, its crown was healthy the year before, and it was not affected by insect defoliation. Annual ring growth in 1966 was less than half that of the previous year. Such trees become susceptible to *Agrilus* attacks. Photo taken in late summer.

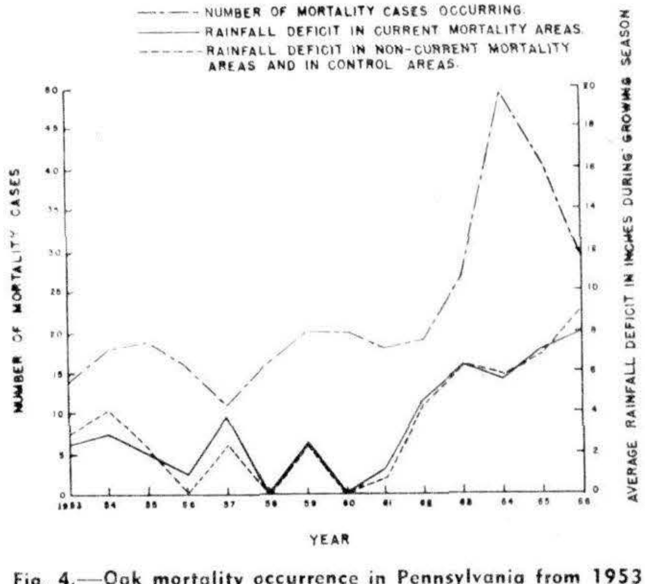


Fig. 4.—Oak mortality occurrence in Pennsylvania from 1953 to 1966 in 70 study areas and corresponding rainfall deficits both within and outside of these areas. The rise in number of mortality cases from 1963 to 1966 was attributed to severe oak leaf tier and fall cankerworm outbreaks from 1964 to 1966 and to severe frost damage over many areas during 1962 and 1963. This insect defoliation was the heaviest recorded in the state since 1953.

b. Seventeen areas showed no mortality from 1962 to 1966 but did so in preceding years after defoliation occurred and when dry periods were not necessarily present.

c. In the remaining 33 areas, heavy defoliation and drought existed at the same time.

d. Rainfall deficits in current mortality areas were virtually the same as those occurring in noncurrent (or previous) mortality areas and in nearby check areas showing no mortality (Fig. 4).

e. Associated species including yellow-poplar, white oak, chestnut oak, red maple, hickory, pitch pine, white pine, and hemlock showed no excessive decline in growth rates and no unusual mortality. Several thousand hemlocks have died in other portions of the state from 1962 to 1966, most such losses being attributed to drought. Red oaks in the same areas that were not insect defoliated were healthy. In addition, many areas in the state, particularly southeastern Pennsylvania, have had much drier conditions than the main centers of oak mortality, yet suffered negligible losses in the red oak group.

7. Three-quarters of the decline and mortality of chestnut oak and white oak was traceable to periodic outbreaks of the pit-making oak scale, *Asterolecanium minus* (Ratz.) (Fig. 5). Effects of the scale on these species have been known for many years (*15*). The death of other chestnut oaks resulted after two to three years of heavy defoliation by the fall cankerworm.

Serious mortality caused by the scale was restricted to nearly pure stands of chestnut oak, its primary host, and generally on the poorest sites. White oak was found severely attacked only when associated with chestnut oak. Trees in the red oak group rarely served as hosts. *Agrilus* attacked and killed trees after two or three years of scale outbreak conditions, when branch dieback had become extensive. White oak mortality, in some remaining cases, was associated with the combined effects of leaf rollers, anthracnose (caused by *Gnomonia veneta* [Sacc. and Speg.] Kleb.), and frost damage.

Oak leaf tier and other defoliation.—In view of the extensive forest damage caused during the past 14 years, the oak leaf tier (Fig. 6) must be rated as the most destructive forest insect defoliator in Pennsylvania. It was found to be the principal defoliator of the red oak group in central Pennsylvania in the mid-1950's. Its relative role before this period was unknown, as it was previously grouped with the whole series of oak leaf rollers. In areas where mortality was determined to be due to the leaf tier, it commonly caused 70-95 percent of the total defoliation (Fig. 7). It has either spread or intensified since 1960 to cause mortality in stands not previously affected.

There is little published material on the leaf tier. Beckwith (*4*) described its stages and seasonal development. The known hosts in Pennsylvania besides red, scarlet, and black oaks, are pin oak (*Q. palustris* Muenchh.), scrub or bear oak (*Q. ilicifolia* Wangenh.), and rarely, chestnut oak. Black oak was not as often in the heavily defoliated category as red and scarlet oaks, consequently, it had a lesser mortality rate.

their decline. Their decline was accelerated where summer defoliation occurred after spring defoliation.

3. A year of moderate spring defoliation resulted in a loss of radial growth of 20 to 30 percent from previous years of negligible defoliation. Continued moderate defoliation usually resulted in further reduction. One year of heavy spring defoliation by insects or frost resulted in a 40 to 70 percent decline from normal growth (Fig. 2). An 85 percent growth reduction from normal was the maximum measured, regardless of the number of years of heavy defoliation prior to tree death. Heavy mid-summer defoliation did not result in radial growth losses of more than 30 percent from normal unless spring defoliation also occurred.

4. The major insects responsible for defoliation in the red oak group, either solely or in combination, were:

Oak leaf tier (*Croesia semipurpurana* [Kearf.])—56 areas
Fall cankerworm (*Alsophila pometaria* [Harris])—17 areas
Forest tent caterpillar (*Malacosoma disstria* Hbn.)—5 areas
Gypsy moth (*Porthetria dispar* [L.])—1 area
Orange-striped oakworm (*Anisota senatoria* [Smith])—1 area

Associated insects which occasionally contributed substantially to defoliation included (the first eight are leaf rollers):

Fruit-tree leaf roller (*Archips argyrospilus* [Wlk.])
Oak webworm (*Archips fervidanus* [Clem.])
Archips griseus Rob.
Argyrotaenia quercifoliana (Fitch)
Croesia albicomana Clem.
Pseudexentera cressoniana Clem.
Olethreutidae—1 unknown species
Gelechiidae—2 unknown species
Linden looper (*Erannis tiliaria* [Harris])
Spring cankerworm (*Paleacrita vernata* [Peck])
Elm spanworm (*Ennomos subsignarius* [Hbn.])
Phigalea titea (Cram.)
Walkingstick (*Diapheromera femorata* [Say])
Variable oak leaf caterpillar (*Heterocampa manteo* [Dbldy.])
Green fruitworm (*Lithophane antennata* [Wlk.])
Orthosia hibisci (Guen.)
Oak skeletonizer (*Bucculatrix ainsliella* Murt.)

Table 2.—Summary of Data from Nine Dominant Oak Mortality Areas, 1953-1966 (All Species of Oak)

1. Average area affected by mortality: 82 acres; range: 30-300 acres.
2. Average duration of mortality period (over 5 percent of oaks killed per year): 1.2 years; range: 1-2 years.
3. Number of recurring mortality cases: 0.
4. Average number of consecutive years of severe frost damage immediately preceding mortality: 1.8; range: 1-2.
5. Number of years of heavy insect defoliation preceding frost damage in (4): 0.
6. Average number of years of moderate insect defoliation preceding frost damage in (4): 1.6; range: 0-3.
7. Number of years of continuing mortality following cessation of frost damage: 0.

5. In the nine areas (#62-70) where only dominant oaks of all species were affected, frost damage was the primary factor leading to mortality (Table 2). Frost had its greatest effects on mature, dominant trees (oaks, ash, and beech being highly susceptible) growing in hollows with poor air drainage, but it was not restricted to such areas. Significant tree damage occurred when temperatures dropped to the mid-20's (°F) or lower during May, especially on two or more consecutive days. Foliage or expanding buds were readily killed. The most critical period for the tree occurred in early May, a few days either before or after bud burst. Mortality to 50 percent or more of the twigs and branches commonly resulted (Fig. 3), and frequently *Agrilus* successfully attacked the tree. In other cases, the major damage caused was the killing of one or two years of twig growth.

6. Drought was not judged to be a major factor causing mortality as evidenced by data from the 70 areas during the five severe drought years of 1962 and 1966.

a. Twenty areas showed either a cessation of mortality, or a decreasing rate, and definite recovery on most survivors during the drought after heavy defoliation ceased.

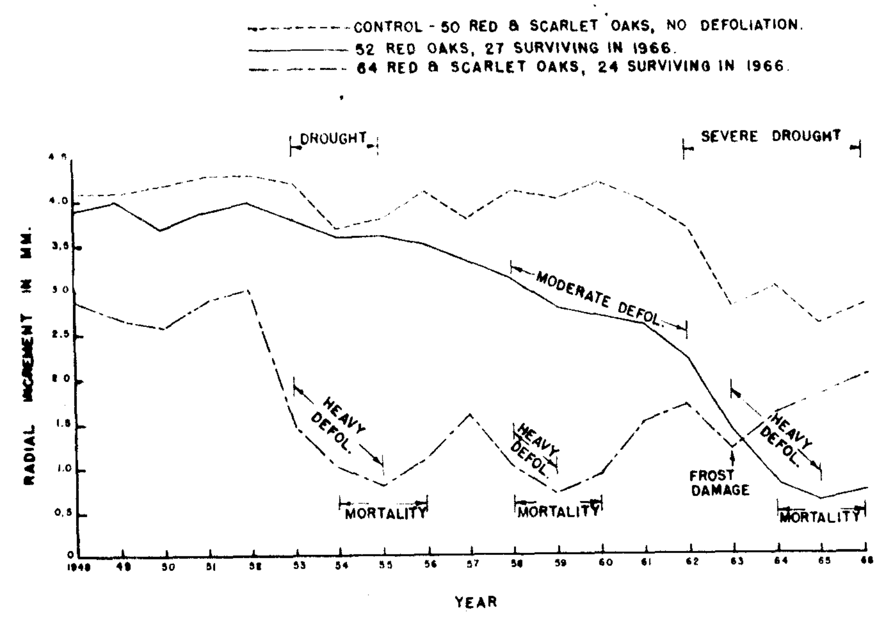


Fig. 2.—Decline in radial growth of red and scarlet oaks in Lycoming County following defoliation by the oak leaf tier and drought. All timber size and crown classes were involved. Precipitation deficits during the growing season: 1953-1955 (average deficit of 4 inches per year); 1962-1966 (average deficit of 6 inches per year).

tree. There would have been little time for the replenishment of energy needed for refoliation. Refoliation in the red oak group occurred after the 60 percent defoliation level. Thus, it is concluded that early spring defoliation of 60 percent or more by insects or frost can be extremely critical for the tree or individual branches.

Decline and mortality in the red oak group has been notably absent to date over most of the western third of Pennsylvania. Leaf tiers and other defoliators have not been abundant in this area.

The role of Agrilus.—The appearance of mortality in oak species was coincident with the girdling action by *Agrilus* larvae. Girdling occurred at numerous places along the entire bole and on branches. Effects of attack were first seen in late July or early August, when the larvae were half to full grown. Tree mortality, evident by yellowing and then browning of leaves, occurred rapidly after girdling was accomplished. A high percentage of tree mortality in any one location occurred within ten days, usually in August. Girdling of the bole was frequently not completed until September or October, due to the extended larval hatching period in the spring and because some trees were attacked by smaller numbers of larvae. Consequently, trees could be found dying through the fall months. A few trees died in the spring after a partial leafing-out and were observed to have been girdled late in the previous year.

The relative importance of *Agrilus* in the overall causes of oak mortality has been debated for several decades. It is not clearly understood what the tree condition must be in order for it to be attractive or for the larvae to succeed in killing it. The borers are always present in oak woodlands in sufficient numbers to successfully attack a declining oak. Attacks are commonly unsuccessful, or repelled, and only succeed on seriously weakened and freshly cut trees, or on injured portions of stems and branches of otherwise healthy trees. In the latter cases, reinfestations may occur for several years, and some trees are eventually girdled and killed in this manner.

In addition to insect and frost defoliations, damage by ice, hail, and scale infestations predisposed trees to *Agrilus* attack. Many trees thus weakened would probably have survived except for this invasion. Thus, *Agrilus* was considered in this study to be a factor of some significance in the widespread and intense nature of oak mortality.

The *Agrilus* egg-laying period occurs at the time of year (late May to late June) when trees are under severe stress from spring defoliation. A reduction in the tree's internal moisture from defoliation during this period may be the factor that allows for successful larval development. Moisture stresses resulting from drought, on the other hand, occurred later in the summer after egg-laying activities (the "attack") were completed. Therefore, current drought conditions and *Agrilus* effects were not closely correlated. Growth reductions caused by drought alone, as observed in check areas, also did not induce *Agrilus* attacks in the following year.

Drought effects.—The worst drought period on record for Pennsylvania occurred from 1962 to 1966, when the average annual precipitation was 34.2 inches—8.0 inches per year below normal. Most of the deficits during this five-year period occurred during the months of the growing season. Between 1942 and 1961, only in one year (1957) was precipitation (35.8″) substantially below normal.

Proper tabulation of these deficiencies during the growing season so as to reveal effects on forest trees is very difficult. Consequently, the gross reactions of known drought-susceptible trees may be a better indicator of drought and its relative impact on all tree species, at least until more definitive data are provided on the effects of moisture deficiency on individual tree species. Mortality obviously induced by drought from 1962 to 1966 was recorded on hemlock, white pine, larch, beech, red maple, and various shade trees in several localities.

The literature does not present an entirely consistent picture on drought effects in the red oak group, as well as on other species. Tryon and True (*19*) found mortality of scarlet oaks on poor sites associated with drought that occurred in previous years, with much of the mortality preceded by a decline period of eight years. A few red oaks were also affected, but associated white pine, hemlock, and the white oak group showed little or no indication of injury. There was no mention of defoliation during the decline period.

Staley (*17,18*) stated that no exceptional drought or series of droughts were discovered to be related to the initiation of red and scarlet oak declines, that declining and dead oaks were found where their roots had penetrated water tables beside springs and streams, and that associated species, including hemlock, white pine, and red maple, showed no similar decline or mortality.

McIntyre and Schnur (*14*) considered chestnut oak, white oak, and northern red oak to be drought resistant. They stated that after the 1930-1931 drought, scarlet oak, white pine, hemlock, and pitch pine suffered 20 to 50 percent mortality in areas of central Pennsylvania. The response in radial growth to precipitation amounts was not consistent, even within species, which indicated to them that a number of factors was probably operative.

Giese et al. (*7*) stated that sugar maple blight was never found in any area that did not have a history of insect defoliation. The authors concluded that below-normal soil moisture levels increase the severity of symptoms, and that defoliation coincidental with a period of drought would result in somewhat greater damage than would occur under other conditions.

There is no doubt that drought, by reducing photosynthetic activity, can affect the growth rate of forest trees (*13,14,19*). Reductions in annual ring growth in trees in the check areas coincided with, or followed, years in which dry conditions occurred (Fig. 2). These yearly growth losses did not exceed 30 percent of normal. There were only slight or no crown symptoms of decline or dieback on oaks following these dry spells. In mortality areas, there was little measurable difference in ring growth loss caused by defoliation in

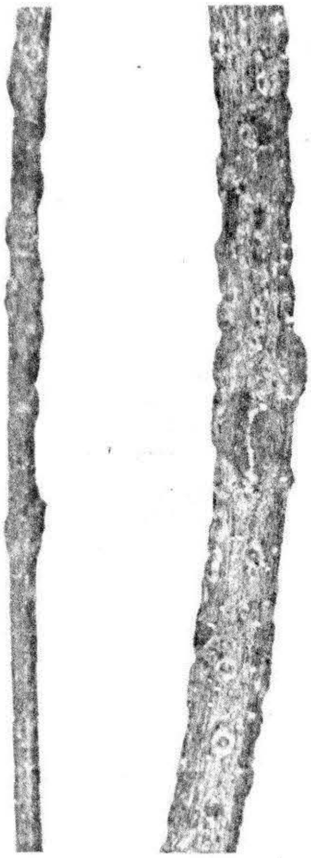
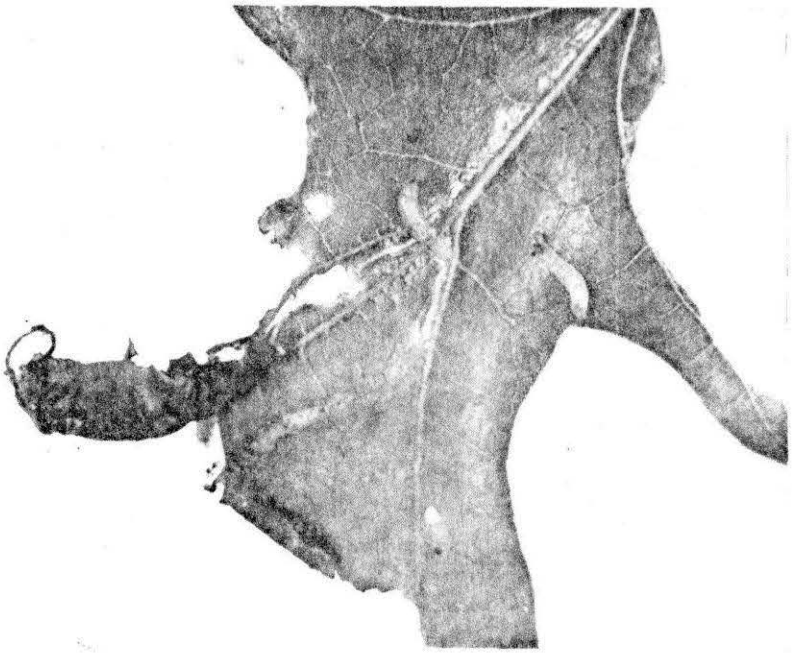


Fig. 5.—The pit-making oak scale on chestnut oak twigs. Scales cause gouty or swollen twigs and frequently the entire crown will die. A union of two or more galls may effectively girdle small twigs or leaf petioles, and larger twigs and branches are killed by 10 to 50 scales per square inch.

Fig. 6.—Larvae and feeding damage of the oak leaf tier.



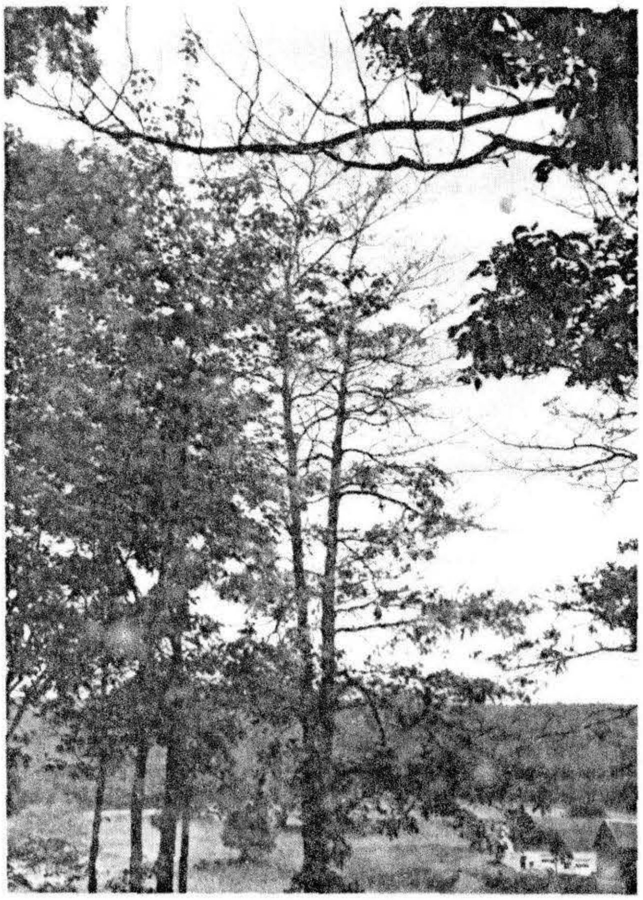


Fig. 7.—Defoliation on scarlet oak caused by the oak leaf tier. Feeding is usually more severe in the upper portion of

Leaf tier larvae hatch in mid to late April, beginning their feeding by boring into expanding buds. The feeding period lasts until late May or early June, and there is one generation a year. Defoliation was greatest on lower slopes and along valley bottoms where the red oak group occurred in nearly pure stands. Many such areas served as "pockets" of infestation from which the insect spread during outbreaks. Several dipterous and hymenopterous parasites of the larva exist, but their effectiveness as a natural control agent has not been demonstrated. Severe freezes on several occasions in early May have resulted in substantial population reductions for a year or two.

Leaf tier infestations may not be noticed from the ground but are readily seen from the air. If defoliation in the upper crown was 60 to 90 percent, that in the lower two-thirds commonly ranged from 20 to 40 percent. This upper crown feeding preference resulted in the branch mortality or dieback that was associated with leaf tier activity. Refoliated leaves were usually stunted and more sparse than normal, and many branches did not refoliate. For tree mortality to occur, however, it required two consecutive years of 60 percent or more defoliation in the spring over nearly the entire crown. This was common during population explosions and resulted in widespread branch mortality and profuse epicormic sprouting. Several studies (*2, 5, 7, 16*) have shown that individual branch mortality can be a direct result of defoliation.

Since much of a tree's food reserves are quickly used up in the flush of spring growth, defoliation shortly after bud burst places a severe stress on the

Table 3.—Mortality in the Red Oak Group Following Heavy Insect Defoliation in Cumberland and Franklin Counties, Pa.

Plot No.	Total No. of trees	No. of oaks[1]	Site index[2]	Aver. d.b.h. (in.)	Range d.b.h. (in.)	Age of stand	Years of heavy defol.	No. of oaks killed[3]					Percent oaks killed
								'59 & '60	'61	'62	'63	'64	
1	45	36	55	7.0	4.2–10.8	45	'58–60, 62	26	3	2	2	0	92
2	38	14	48	8.4	5.3–14.0	70	'58–60	6	1	0	0	1	57
3	31	9	57	10.1	5.4–14.7	75	'58–60, 62	1	0	3	0	0	44
4	38	7	53	8.7	4.7–15.9	75	'58–60, 62	0	0	2	0	0	29
5	36	7	57	9.0	4.7–14.9	70	'58 60	4	3	0	0	0	100
6	40	28	63	7.4	4.9–13.8	48	'58–60, 62	9	5	6	0	1	75
7	57	47	56	7.8	5.1–12.5	45	'58–60, 62	5	3	6	1	1	34
8	25	9	61	10.9	6.0–25.8	80	'58–60	1	0	0	0	0	11
9	29	13	61	10.1	5.0–19.8	80	'58–60	8	0	0	0	0	61
10	16	11	57	10.2	5.2–18.0	75	'58–60	4	0	0	0	0	36
11	9	10	56	10.2	5.2–16.2	70	'58–60	1	0	0	0	0	10
12	27	17	60	11.4	5.3–18.0	70	'58–60	0	2	0	0	0	12
13	33	13	69	11.9	5.0–22.1	72	'58–60	2	3	2	0	1	61
14	23	4	70	12.2	5.8–25.0	70	'58–60	0	2	1	0	0	75

[1] There were a total of 197 scarlet oaks, 21 black oaks, and 7 red oaks in these plots.
[2] Average height in feet of dominant trees at 50 years of age.
[3] There was no mortality in 1965 and 1966.

nondrought years and that caused by equal amounts of defoliation in and following drought years.

It is concluded from this study that droughts are not a primary causal agent in the present oak decline and mortality situation in Pennsylvania, but that their effects are roughly equal to those caused by moderate defoliation. The effects of abnormally dry periods since 1930 have appeared to be primarily indirect, that of increasing the probability of severe outbreaks of oak defoliators.

Other factors.—Representative data from each mortality area on aspect, slope, soil condition, tree age, crown class, relative vigor prior to heavy defoliation, site index, and stand density showed no obvious or consistent correlation to decline and mortality. Soils in the red oak group areas of Pennsylvania range from silty clay loams to sandy loams and are frequently rocky. Decline and mortality occurred widely on well-drained soils and, conversely, nondeclining trees were found on poor soils.

Armillaria mellea (Vahl.) Quel. was not consistently found on dying trees. Staley (*17,18*) concluded that root rot organisms associated with oak decline were of a secondary nature and weakly pathogenic, that no fungi were consistently isolated from dead branch tissue, and that the role of climatic and edaphic factors was to influence the severity of defoliation effects.

Opinions are frequently advanced that the current red oak group decline is an "ecological" problem, the result of advancing age of stands. Much of the present mixed oak forest in Pennsylvania (58 percent of the forested area) was originally a climax type comprising chestnut, white oak, white pine, hemlock, and chestnut oak, with the red oak group a relatively minor component. Heavy cuttings, followed by fire, and chestnut blight, left practically pure stands of less tolerant red, scarlet, and black oaks. Though many of these stands are now reaching maturity on the sites they occupy, the mere fact of approaching maturity does not explain the sudden concurrent dying of oaks over wide areas. It seems more logical and meaningful to state that the dense red oak group stands have now existed for a sufficiently long period to make them increasingly susceptible to buildups of destructive defoliators which were formerly of less concern.

Recovery from decline.—In mortality areas 1 and 2 (Fig. 1) where more intensive studies were made following heavy forest tent caterpillar defoliation from 1958 to 1960, mortality in the red oak group averaged 52 percent, with a range of 10 to 100 percent (Table 3). Other species, including white oak and chestnut oak, were unaffected. Some plots had additional defoliation in 1962 by oak leaf tiers and linden loopers. A summarization showed that 82 percent of the total mortality had occurred by the time heavy defoliation ceased, and 98 percent of the mortality was over within two years of cessation of defoliation.

Radial growth measurements indicated that recovery of 107 of the surviving scarlet, black, and red oaks began the year after heavy defoliation ceased (Fig. 8).

The rates of crown recovery from 1961 to 1966

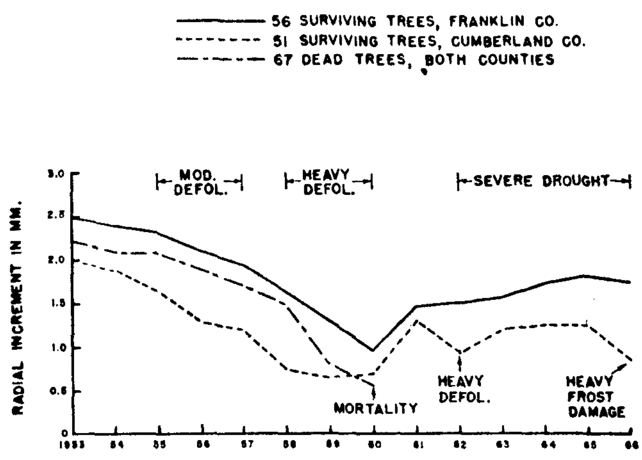


Fig. 8.—Decline and recovery of radial growth of scarlet, black, and red oaks following heavy defoliation by the forest tent caterpillar in Cumberland and Franklin Counties. All timber size and crown classes were involved. Radial growth was fairly constant prior to 1953. Precipitation deficits during the growing season: 1953-1954 (average deficit of 5 inches per year); 1957 (deficit of 4 inches); 1962-1966 (average deficit of 8½ inches per year).

were measured yearly for the surviving oaks. Crown recovery proved to be a slow process and was not consistent with radial growth recovery. Thirty-two percent of the crowns showed measurable improvement, but none advanced more than one category; 63 percent showed no measurable recovery or further decline; 5 percent continued to decline.

The method of crown measurement was not considered as adequate in determining recovery as it was in showing decline rates. Many trees that had declined to the last category and then began recovery, for example, had more than sufficient amounts of epicormic branching to sustain the tree. Many years would elapse before this foliage would approach that of a normal crown. It is probably more accurate to state that as long as no further crown dieback is occurring, recovery is taking place.

Considering the relatively poor tree and stand conditions in these areas and severe drought from 1962 to 1966, recovery after defoliation ceased was surprisingly good. A similar pattern was evident in other mortality areas. Crown recovery in many areas, however, has been inhibited by recurring leaf tier defoliation.

Recommended Management Practices

Although oak leaf rollers and other common lepidopterous oak defoliators may be controlled with DDT sprays, the use of DDT in aerial insect control operations has been criticized in many quarters during recent years. Other insecticides have not been adequately tested on the leaf roller group. In the only two known DDT control operations, leaf tier larvae were reduced by 91 percent and 97 percent. Further decline and mortality ceased in the sprayed areas, whereas it continued in untreated adjoining stands.

In analyzing the impact of oak mortality in forest management, it becomes obvious that spraying to preclude such losses should only be considered as a measure to prevent mortality of high quality trees. There is an immense acreage of low quality red oak group species in Pennsylvania, and direct control in such areas is questionable.

The solution to the problem in decline areas lies largely in management. Indications are that the mortality problem will continue until the red oak group is reduced to a more natural level such as that existing in the climax type. Each area presents its own management problems, but a few general guidelines can be drawn.

- In intermediate cuttings, an effort should be made to reduce the red oak group to that of a minor stand component. Red and black oaks should be left in preference to scarlet oak. In several areas of past mortality where 5 to 15 percent of the red oak group survived, trees were not seriously invaded later from nearby outbreaks. Natural regeneration in most of the mortality areas has tended towards white pine, yellow-poplar, and red maple. Such species should be favored to allow for the propagation of a more insect-resistant stand.

- Success with intermediate cuttings in many decline areas has been hampered by numerous factors, among the ... stands from persistent defoliations. Clearcutting, therefore, is probably the best solution for most decline areas, depending on other management considerations. Stands predominantly scarlet oak should especially be clearcut if about 80 years of age. Cull caused by decay usually results in the serious breakup of such stands over 80 years old (9).

- Silvicultural control of the pit-making oak scale on poor sites (rocky upper slopes and ridges) is probably not feasible. Chestnut oak on such sites is one of the few species that survives, has little commercial value due to poor form, and in many cases is inaccessible. On better sites where chestnut oak has declined from scale attacks, logging operations should be aimed at removing as much of the species as possible, leaving the more vigorous white oaks. Chemical control of the scale is possible but not economical.

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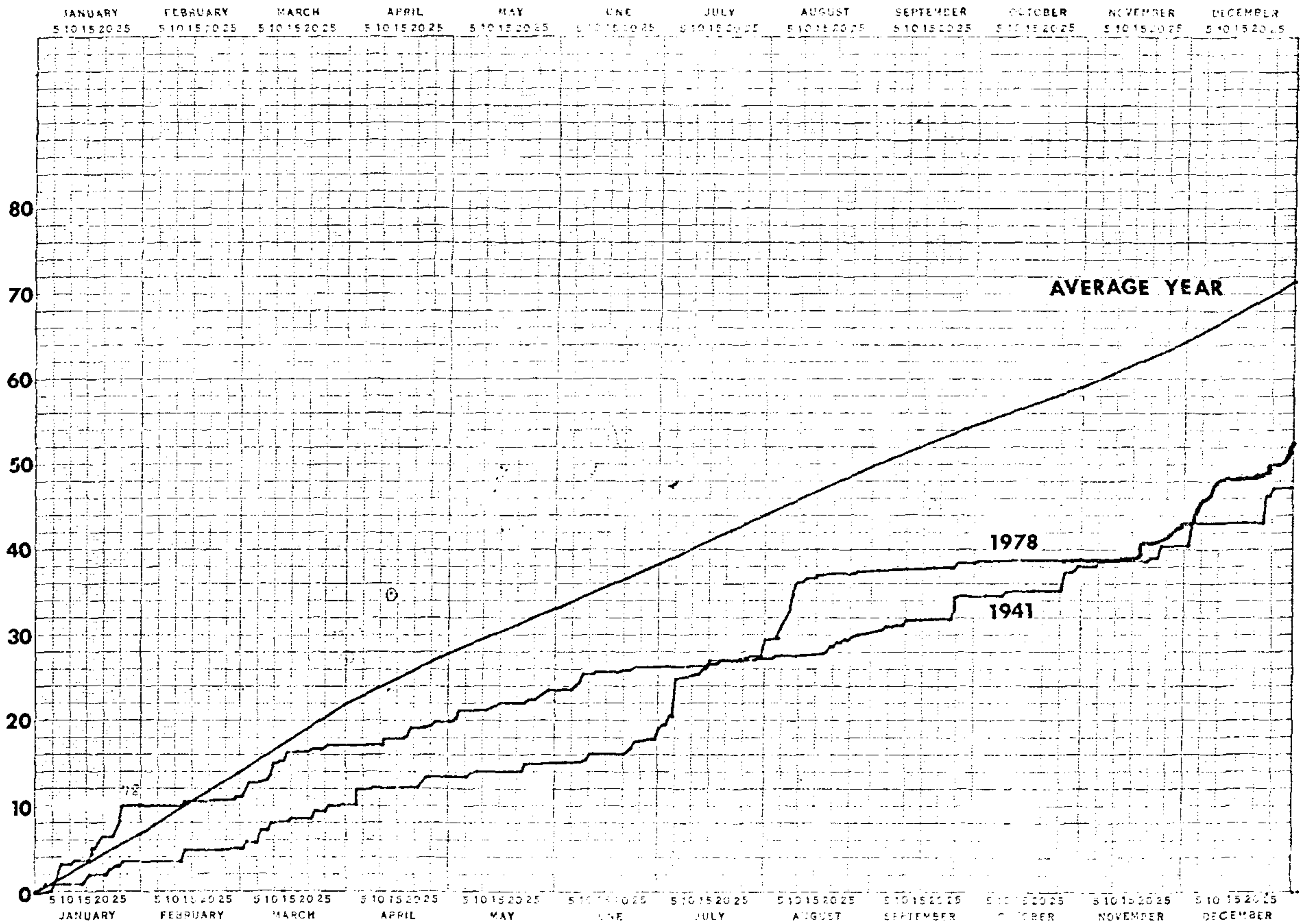

AVERAGE YEAR
1978
1941
80
70
60
50
40
30
20
10
0
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JULY
AUGUST
SEPTEMBER
NOVEMBER
DECEMBER

Attachment 4

Dormant Season		Growing Season	
Year	Inches rain	Year	Inches rain
70	32.58	78	21.03
67	32.83	68	25.84
78	35.69	65	28.86
68	36.73	77	29.85
65	36.77	73	31.31
66	36.83	74	31.48
76	37.38	66	31.58
72	38.08	71	34.68
77	39.4	72	35.29
71	39.64	64	35.82
69	40.17	75	36.56
75	47.72	70	37.52
64	49.18	69	39.57
79	50.67	76	42.75
73	52.68	67	45.22
74	55.28		

Attachment 5

Month	1973	1974	1975	1976	1977	1978	1979
J					9		
F				6	8	2	
M			3	1		6	
A							
M					5		
J			3	4	2	7	
J							
A							
S						3	
O						3	
N							
D							

(Year spans the columns 1973–1979.)

1-9 = -- driest month in 44 years